Reimagining the Seafood Industry with Artificial Intelligence: Innovations for Efficiency and Sustainability

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Abstract

The seafood industry plays a substantial role in contributing to the Gross Domestic Product of India. This sector provides a source of foreign exchange, with marine product exports growing at around 7.13 per cent over the last two decades. The industry supports more than 30 million people for their livelihood and employment through its direct and allied activities. Seafood is a vital component of the global diet, providing high-quality protein, Omega-3 fatty acids, and micronutrients. Transformations from traditional methods to modern technology in harvesting,peeling,cleaning,freezing,processing, packing and marketing are necessary to improve the efficiency of the seafood industry in India. Because of rising demand, scarcityof resources, environmentalpressure, and market volatility challenges artificial intelligence is emerging as a vital tool for smarter, resilient and sustainable seafood production.Artificial Intelligence technologies such as computer vision, machine learning, robotics, predictive analytics, and IoT-integrated monitoring systems are revamping seafood operations through real-time insights and automated processes. In wildcapture fisheries, AI supports sustainable stock management by predictingthe availability of fish, optimising fishing routes, and helpingcombat illegal and unregulated fishing. AI-enabled automation reduces post-harvest losses, assures cold-chain integrity, improves grading accuracy, and enhances product quality assessment. Through sophisticated fraud detection, blockchain integration, and digital documentation, AI enhances traceability and transparency, boosting customer confidence and fulfilling international sustainability standards.Thisstudy tried to examine how AI-driven innovations are transforming the seafood sector by boosting operational effectiveness, bolstering sustainable practices, and enhancing decision-making in the seafood value chain.

Keywords: Artificial Intelligence, Predictive analytics, Blockchain Integration

Introduction

The seafood sector plays a pivotal role in the international economyby providing millions of people access to food, employment and money (Fox et al. 2018). The industry is one of the most significant interconnected areas of the agri-food sector, providing millions of people with their protein intake and supporting the economic stability of those who depend on it for their livelihood.Another highlighting factor in the case of seafood is the concern for the local food tradition, which is often associated with the security and sustainability ofthe local economy(Kasza, 2024). The seafood sector is very important in the international economy and the global food supply chain. In order to accommodate the various needs and desires of the customers, the seafood companies should be involved in specialised business operations like catching, processing, and promoting. These companies deal with very complicated natural and business environments in order to get and promote a variety of sea products. The seafood companies are eager to deliver the best-quality seafood to people all over the globe(Abhirami,2023). It also contributes to international trade, cultural identity, nutritional values, and the safeguarding of traditional livelihood. But, a high rate of population growth, increasing demand for high-quality seafood items, escalates pressure on marine ecosystems and there is a limitation in existing operational systems. These factors include resource depletion from Illegal, Unreported, and Unregulated fishing, inefficiencies in aquaculture production, cold chain management difficulties, post-harvest losses, and the continued inability to provide end-to-end traceability from sea to consumer. Contributing to these pressures is the growing influence of climate variability, trade disruptions driven by geopolitical tensions, and demands for commodity transparency and compliance with regulations.Traditional managerial systems and the present supply chain mechanism are inadequate in addressing the complex nature of these constraints. Lack of real-time monitoring systems, low data utilisation and inconsistent regulatory enforcement reduced the capacity of the sector to evolve in alignment with the present market needs and environmental sustainability. To overcome this, artificial intelligence and digital technologies like machine learning, sensor-based automation, deep learning, and AI-based blockchain systems provide a shift capable of operational and logistical frameworks. The technologies based on artificial intelligence facilitate accuracy, speed, quality, predictiveness and responsiveness.

The application of artificial intelligence holds a substantial transformative capacity across the international seafood industry. Automated habitat regulation, intelligent feeding systems and AI-based disease detection can improve the efficiency of production and sustainability in aquaculture and mariculture. Predictive analysis, aided by satellite data and AI-supported monitoring systems, can enhance surveillance, detect IUU practices, and inform environmental stock assessments. An organisation called 'Global Fishing Watch Platform' collaborated with Google, Oceana and Sky truth-a digital mapping non-profit organisation, tocombine AI and satellite data for understanding the fishing activity all over the world. This collaboration helps to track IUU vessels, poaching, overfishing and at – sea transhipments in a more precise way. AI monitoring made it possible to collect data on the size of fishing vessels and types of gear used for fishing (Chrispin, 2020).At the stage of processing and distribution, quality inspection by robots and digital cold chain monitoring strengthens product integrity, reduces wastage and upgrades market competitiveness.The evaluation of seafood quality is a multifaceted process that combines sensory, physical, and microbial methods to ensure safety and consumer satisfaction. Sensory evaluation with AI gives a valuable and comprehensive understanding of the freshness and overall quality of the seafood. The Torry Sensory Assessment Scheme is particularly noteworthy for its systematic scoring system that quantifies the freshness and quality of seafood items(Preethi, 2024). Besides, AI-driven traceability architectures integrated with blockchain and IoT devices give a platform of transparency for the seafood supply networks that boost consumer confidence, regulatory accountability, and access to international markets. The industry is limited by capital investment needs, cybersecurity risks, algorithmic bias, ethical concerns over the displacement of coastal communities, and unequal digital capacity between developed and developing world economies. Absence of standards over global interoperability and regulatory fragmentation adds to the complexity of adoption strategies. These complexities place AI not just as a technological upgrade but as a cross-sector reformist mechanism that necessitates collaboration among multi-stakeholders, inclusive policy frameworks, and deployment models sensitive to different contexts.

The demand for seafood is increasing rapidly due to the high rate of population growth and the changing consumer preferences. Due to high demand, it is putting high pressure on raw materials and accelerating a shift towards mariculture and aquaculture and efficient value chains. The seafood industry faces many issues and challenges, like

overfishing, environmental changes, high production costs, lack of availability of skilled labour, inadequate infrastructure facilities, inefficient supply chain, management of waste, etc.

Technologies with AI, such as computer vision and machine learning, have immense potential for analysing a large volume of data related to the fish industry. By leveraging AI algorithms, fish farmers can gain valuable insights intothe growth patterns of fish, feeding behaviour, and environmental factors affecting this industry(Madal, 2024). The use of tools like drones, micro-sensors, bionic robots, remote cameras, intelligent sorting, energy-saving processing equipment, statistical equipment, and algorithms will minimise human intervention and maximise productivity. In addition, the use of technologies in the aquaculture sector's value chain to ensure effectiveness in traceability, feeding, disease detection, growth prediction, environmental monitoring, market information utilisation, and other techniques is instrumental in boosting productivity in the sector. It is on this basis that the future of aquaculture operations with minimum human involvement and maximum maintenance hinges on innovation (Mustapha,2021)

Digital technologies bring operational benefits for the global value chain,enhance efficiencies and productivity, reduce waste, contamination and food fraud. The AI technology is used in the fisheries industry to advance human-centric solutions (Neil,2023)

Seafood products have traditionally been classified as one of the more perishable of foodstuffs. The realisation of the need to preserve the products arises from the fact that the fishing boats harvest the seafood at long distances from the areas of consumption. There is also the realisation of the demand from consumers who require high-quality fishery products with low levels of alteration of the nutrient content. These needs also extend to fishery products from aquaculture, which have to be preserved to be transported to distant areas of consumption (Kontominas.2021)

Objectives of the Study

1. To assess the global challenges in the seafood industry and their impacts on the economy.
2. To analyse the AI technologies that are applicable for seafood harvesting, production, processing and distribution.

3. To evaluate the potential of AI solutions in enhancing quality control, food safety, transparency, and sustainability across the seafood industry.

Key Challenges in the Global Seafood Industry

The seafood industry, which depends on traditional systems, is facing many challenges and interconnected constraints across the seafood value chain from harvesting to market. These challenges may lead to inefficiency in production, poor quality, high cost of production, and environmental problems. Production and sourcing, post-harvest losses, inefficiency in the supply chain and unstable economic conditions are some of the constraints in the seafood industry.

Depletion of stock and overfishing, without considering the sustainability, will adversely affect the availability of the raw material. While following traditional practices, fishing harbours and landing centres lack basic amenities such as proper pre-processing facilities, cold storage, waste-disposal systems, and hygienic auction platforms, leading to spoilage and deterioration in the quality of the catch. Traditional methods used for peeling, cleaning, processing and packing often lead to environmental issues. Some areas of this industry still follow unscientific and outdated methods, which may hinder productivity. Lack of cold storage and insufficient transport and logistics facilities in the traditional system result in quality degradation and substantial post-harvest losses.

Harvest and Post-Harvest Challenges

Harvest and post-harvest losses in the seafood industry are a barrier to economic efficiency and food security because of the highly perishable nature of marine products. Very high levels of post-harvest loss occur during pre-processing, processing, storage and transportation of fishery products (Rahman, 2013). Losses can occur at different stages, from harvesting to marketing, due to the inadequacy of infrastructure, improper hygiene practices, temperature fluctuations and inefficient transportation systems. These issues lead to physical loss, quality loss, and nutritional loss, which impact the income of the people who depend on the seafood industry for their livelihood.Fish and seafood are readily accessible sources of animal protein, but this alternative is also threatened by poor post-harvest techniques in many countries, which leadto massive economic losses(Getu A,2015). High rate of spoilage limits the consumer demand, access to nutritional values and weakens global competitiveness due

to rejection of seafood products in domestic and international markets. Investment in cold storage facilities and improved preservation practices is required to address these types of challenges. Integration of modern technologies like smart packaging, IoT-based temperature monitoring, and predictive analytics is necessary to enhance overall supply chain efficiency and sustainability.

Technological challenges in processing

The seafood industry is going through a digital transformation, though challenges are facing the adoption of advanced technologies. Capture fisheries, mariculture and processing units still operate with traditional systems, leading to a slow shift towards automation, smart monitoring and data-driven decision making. Lack of digital literacy among workers is an issue in the adoption of new technology.Lack of automation in processing is an important issue in this industry. Manual sorting, grading and filleting are time-consuming and increase labour dependency. Shortage of modern equipment limits productivity compared to advanced markets.Inadequate infrastructure facilities, such as limited access to power and internet, further restrict the integration of new technologies like satellite tracking, IoT sensors and cloud platforms. The high cost of technological implementation is another problemwith this industry. A big investment is required for the automation of processing machinery, artificial intelligence and traceability systems, which may not be affordable for small-scale enterprises. These challenges hamper the efficiency, competitiveness and sustainability in the seafood sector.

Economic and market challenges

The seafood industry faces serious market pressure from global competition, consumer expectations and regulatory demands on producers, processors and distributors. Price variation due to seasonal catches, unexpected climate changes and cyclones, and supply shortages are major threats to this particular industry. It is hard to plan an investment and a business forecast. As buyers demand product quality, transparency and sustainability, many producers struggle with low resources and market structure. This leads to price volatility, unpredictable market access, and a high cost of production. Sometimes cold chain gap leads to spoilage. Tariffs, export bans, import restrictions, and sanitary standards limit access to seafood and value-added items. Emerging low-cost producers from countries like Thailand and Vietnam intensify price competition. The seafood market has been hampered by the lack

of pricing stability, fragmented competition, strict compliance and consumer expectations. The lack of access to the information of the market, sustainability requirements, and global pricing pressures make the scenario challenging for the small to mid-scale seafood producers.

Ecological and environmental challenges.

Overfishing and stock depletion are major challenges faced by the industry. Excessive harvesting of commercial species, especially tuna, salmon, and cod, leads to the collapse of the stock. Illegal and unregulated catching worsens depletion, and it is a threat to the ecosystem and biodiversity. Lack of enforcement and mismanagement of fisheries in the ocean are quickening the imbalance. Plastic, chemicals and oil spills contaminate the ecosystem. Microplastics infiltrate the food chain, raising health and export quality concerns. Climate change seriously threatens the seafood industry due to high ocean temperatures, acidification and extreme weather. Warmer water pushes fish to deeper or cooler areas, changing catch patterns. A warming ocean and acidification lead to coral bleaching and damage the nurseries of many marine species. Irregular and unexpected cyclones reduce the fishing days that affect the livelihood of the people who depend on the seafood industry. All these ecological and environmental challenges are affecting the profitability and sustainability of this industry.

Artificial Intelligence integration across the seafood value chain

Smart fisheries and ocean monitoring

Application of artificial intelligence is transforming the traditional fishing methods to smart fishing that helps enhance the sustainability, efficiency and ecological stewardship in the seafood industry. Innovations such as image recognition systems and computer vision help species identification and population counting by drones and AI-enabled cameras. Availability and migration pattern of fish and the ideal harvesting period can be estimated with the help of machine learning algorithms. Real-time tracking of parameters like temperature, salinity and oxygen levels with IoT sensor networks through smart buoys and under acoustic devices improves habitat assessment and detection of harmful events. Smart nets with AI sensors can identify unwanted species before capture, support marine conservation and legal compliance. Automated identification system detects suspicious vessel activities that help the government and responsible authorities to monitor IUU.AI-enhanced traceability tools integrated with blockchain promote transparency along the seafood supply

chain. Collectively, these technologies show that AI forms an integral enabler for modernising fisheries management and promoting sustainable ocean governance.

Aquaculture and mariculture with AI

Artificial Intelligence (AI) assists marine aquaculture in the remote control of marine aquaculture monitors, helping decision-making in farming. It estimates data from water sensors in real-time and adjusts water quality parameters, which facilitate ideal growth conditions for marine organisms. Optimised farming and feeding increase growth rates, yield and productivity. Data from fish cameras in real-time enables users to track fish behaviours and predict irregularities. It also helps in environmental assessments in mariculture because that analyses and predicts negative algae outgrowths in water. Artificial Intelligence enables marine aquaculture net cleaning and seabed inspections with marine aquaculture drones and robots. AI also enhances marine aquaculture safety and increases efficiency. It helps in data collection from biological and environmental processes in marine aquaculture and enables a precision marine aquaculture approach.

Processing and Quality Control in the Seafood Industry with AI

Artificial intelligence improves the processing and quality control by automating sorting, grading, packing systems and inspection in the seafood sector so that the industry can enhance accuracy and consistency. Automated inspection helps to reduce human error. Real-time monitoring and spoilage detection protect freshness, taste and nutritional values. AIsupport higher processing speed and productivity. Precision cutting helps to reduce trimming loss and grade the product based on size and texture. This replaces slow and inconsistent manual inspection. AI-enabled robotics assist in filleting, de-shelling, deboning, and portioning operations with precision, reducing waste and improving product yield. In quality control, artificial intelligence systems are constantly monitoring the indicators of freshness, like temperature, texture change, and microbial activity at the time of storage. Advanced X-rays in deep learning detect foreign matter and quality issues that can be difficult for human inspectors to see. AI-driven cameras and lasers sort items to remove defective or off-grade seafood. These facilities detect the signs of spoilage and contamination. Predictive analytics affords an estimate of the shelf life and recommends processing adjustments to maintain optimum product quality. AI-powered traceability systems maintain digital records right from raw material intake to final packaging. This helps

in complying with international standards of food safety and makes product recall faster and more accurate, if required.

AI-Enhanced supply chain, Logistics and Integration in the seafood industry

The introduction of artificial intelligence in the seafood sector is replacing the traditional methods, facilitating a transition from the old techniques of fragmented and unorganised methods to smart, predictive, intelligent and internationally connected value chains. Digital technologies allow transparency, automation and analytical methods that are important in the seafood industry because of the perishable nature of raw materials and products, the complexity of distribution, and stringent regulatory measures. AI upgrades every stage of the seafood supply chain from ocean to plate. In harvesting and resource planning, AI uses oceanographic data, images from satellites, and analyses previous data to understand the fish stock movements and availability of raw materials. Predictive modelling reduces wastage of resources by helping vessels focus on areas where they are likely to have a good catch. It also promotes responsible fishing by preventing overfishing. This maximises productivity and supports sustainability goals and global fishery management standards.

Seafood processing often is a labour-intensiveoperation, especially when it comes to grading, filleting, or contamination control. With the help of computer vision systems powered by AI, the task of species sorting, defect detection, assessment of freshnessor identification of pathogens can be done with even greater accuracy. This allows for a consistency level of product quality, greater processing speed, and a reduced number of recalls due to human-related issues. Machine learning algorithms also help the processing plant stay on top of standardisation.Inventory management with the help of AI enables knowing about the consumption and demand of the product and helps the processors and distributors to regulate the stock levels. Blockchain, combined with AI, generates tracking for each product from catch to consumer. It also facilitates tamper-proof traceability records. This helps to reduce data fragmentation, bring down seafood fraud, and deepen supply chain credibility, especially for export markets where certification is compulsory.

AI-driven B2B marketplaces bridge fishermen, processors, wholesalers, and retailers as they connect directly without middlemen, who often take unfair advantages and can lessen exploitation. Recommendation systems also connect sellers automatically with their

corresponding potential buyers according to species, quantities, locations, and certified categories. This will greatly benefit small-scale fishermen since they will be accorded access to export markets, which they previously could not reach.

Conclusion

The support of Artificial Intelligence in the seafood sector is transforming the value chain from harvesting to market. Automated inspection detects defects and contaminationthat help improve the quality and safety more accurately than a manual check. Spoilage can be reduced by the real-time monitoring of temperature and hygiene in the industry. Post-harvest losses can be reduced with the help of predictive analytics. It helps to maximise storage, transport and shelf-life management. Higher efficiency and productivity in the seafood industry can be achieved with the help of robotics and automation that speed up peeling and packing. AI-powered stock assessment promotes sustainable fishing. Bycatch vision systems and sensors help avoid non-targeted catch. Blockchain and AI systems promote transparency and traceability, which reduces fraud and illegal fishing. Improved worker safety can be achieved with the support of AI-assisted machinery. Using AI in the seafood industry can achieve higher quality consistency and stronger competitiveness in the face of market change, giving an edge in global trade.

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